Attributes of Indoor Environmental Quality to Earth-sheltered Building Design

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ABSTRACT

This paper discusses the environmental attributes to underground building shape and configuration, materials, structures, use, maintenance, lighting, occupancy, and management. These criteria are hypothesized to be of more influences on the building environment in the cases of underground spaces than in the aboveground. The aim is to approach and link together the many recent architectural and engineering factors that affect indoor environmental quality (IEQ) as a contribution to the affordability and sustainability of present earth sheltered building design and development. To attain its goals, the study develops a conceptual micro-framework of healthy buildings' parameters and economic aspects for evaluating links between sustainable construction and outcomes of health, productivity, and affordability. The conclusion indicates the importance of integrating appropriate technologies into earth sheltered space design, while the recommendations conform with environmental organizations and policies' directives in both their short and long-term development plans to provide affordable and healthy earth sheltered interiors. (150 words)

KEYWORDS: underground spaces, architectural design, sustainability, indoor environmental quality

INTRODUCTION

Humans have been utilizing the underground space for thousands of years, and many fruitful examples of enduring techniques throughout the world have been developed. There are as many kinds of earth buildings methods as there are variations in soil, climatic, and cultural conditions. Increasingly, it is being recognized for its green building aspects. Earth is known as a non-toxic material and readily available - often directly from the site. The thermal mass of thick walls can lower heating and cooling needs, as well as provide sound insulation, structural integrity, good fire protection and natural beauty. Conceptually, the built environment includes all of the physical structures engineered and built by people—the places where we live, work, and play. These edifices include our homes, workplaces, schools, parks, and transit arrangements (Dearry, 2004, p. 600).

Hypothesis

Green affordable housing can promote a "virtuous cycle," where high-quality housing lower operating costs and healthier indoor and outdoor environments act synergistically to improve the quality of life for residents. In this sense, attributes of the indoor environmental quality and the way they should affect building shape and configuration, materials and structures, use and maintenance, lighting and occupancy, and management factors are hypothesized to be of more influences on the building environment in the cases of underground spaces than in the aboveground, Fig. 1.

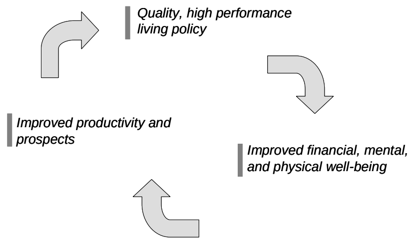

Figure1. Virtuous cycle of Green housing as illustrated by K. O'Brien's presentation to the Green Affordable Housing Conf. (Stewart, 2004).

In addition, increasing concerns for energy efficiency, building durability, and indoor environmental quality can possibly move residential design and construction into a new era in terms of:

- consumer demands and performance expectations;
- more stringent building and energy codes to be adopted; and
- new building products and advances to be introduced.

Aims

The aim of this paper is to approach and link together the many recent architectural and engineering factors that affect indoor environmental quality (IEQ) as a contribution to the affordability and sustainability of present earth sheltered building design and development. Of the many confronted environmental problems, this paper tackles the issues of which architects should especially be aware to minimize health effects caused by pollutants and contaminants in underground placements. These issues include environmental design criteria and construction attributes of the functional requirements. Suspected risk factors of HVAC types and building features are also discussed.

Driving Forces and Contradictions

Maintaining indoor environmental quality in earth-sheltered building design can help achieve the following:

a) Reduced environmental impact by minimizing the negative long-term effect on the environment, reducing unnecessary resource extraction and thus conserving natural resources, and reducing waste generation.
b) Reduced impacts to environmental quality by providing for interior environmental quality, by selecting low-emitting materials, and indoor air quality monitors.
c) Reduced construction and maintenance costs by specifying easy-to-maintain materials and pursuing alternative funding opportunities, by improving lighting systems, mitigating noise, improving occupant performance, reducing absenteeism, achieving energy savings, and reducing replacement of materials, Fig. 2.

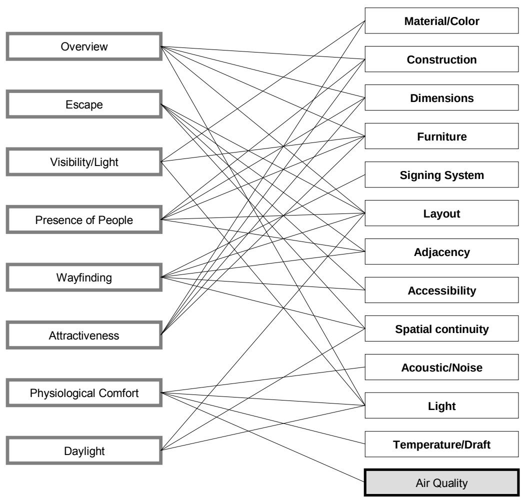

Figure 2. Tentative relationship diagram.

Interiors are among the six key principles of achieving high performance buildings. Because the average people spend more than 90% of their time indoors, the buildings we work and live in greatly affect our lives. In the last thirty years, the building industry has developed new techniques and materials which make it possible to construct much more efficient buildings with very little increase to the upfront construction costs. These practices yield returns as high as 80% on ongoing energy costs, which typically result in very short payback on any initial investment. The concept of high performance or green building incorporates a variety of strategies during the design, construction and operation of building projects. Green building and energy efficient design encompass six key areas include architecture and design; building materials; land use; energy use; water use; and interiors (Durmisevic, 2002, pp. 37-9; 41-3).

On the other hand, the major trigger for earth sheltered space usage is the growing international concern over the balancing of economic development versus environmental degradation and world natural resource limitations. These revolve around a number of key issues:

- The increasing consumption of energy compared to the limited reserves of fossil fuels available to meet future demand.
- Effect on global climate of burning fossil fuels.
- The pollution of the environment from the by-products of industrial development.
- There are many positive literary and scientific visions of underground uses in the future.
- Safe disposal of hazardous wastes generated by industrial and military activities.
- Positive and negative visions of future underground development are subjects of science fiction writers (Esaki, 2005, pp. 2-11).

Methodology

To achieve its aims, the study demonstrates some recent international and local standards and regulations regarding the indoor environmental quality and living conditions in earth sheltered spaces. It discusses the emission of threatening pollutants and their health effects. In addition, the paper provides a brief description of some of the common ventilation problems reported in underground placement, Fig. 3.

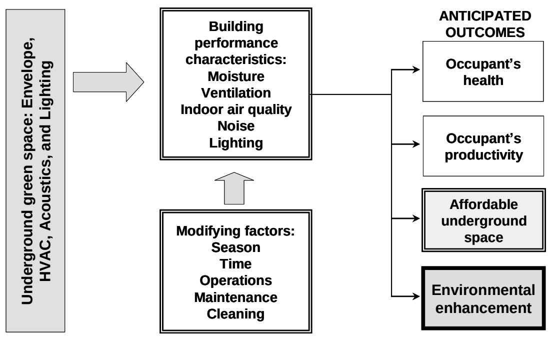

Figure 3. Conceptual model for evaluating links between green buildings and outcomes for health, productivity, and affordability in underground placements. (U.S. National Research Council of the National Academies. 2006).

Underground design requirements.

Underground design requirements are tackled in the broadest sense as the means by which an architect creates a space. They are defined as those elements that are in the hand of an architect, and thus can be manipulated by a designer. According to Durmisevic, two groups of aspects - formal and functional - can be defined and specified. If a space is to be reduced to its basic components, it could be seen through those two main aspects, given in Fig. 4, 5, 6. (Durmisevic, 2002, pp. 37-9; 41-3)

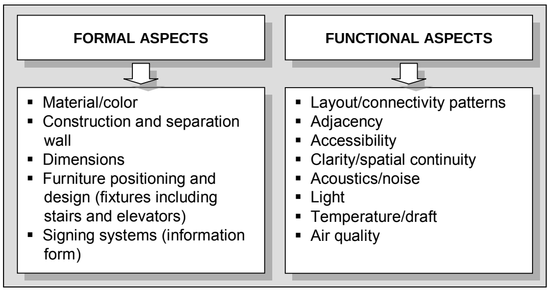

Figure 4. Environmental quality, among the main standard and additional requirements embedded in a form and function aspects of underground space design (Durmisevic, 2002)

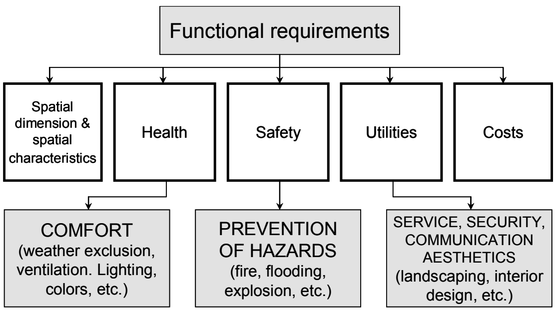

Figure 5. Attributes of functional requirements in underground spaces.

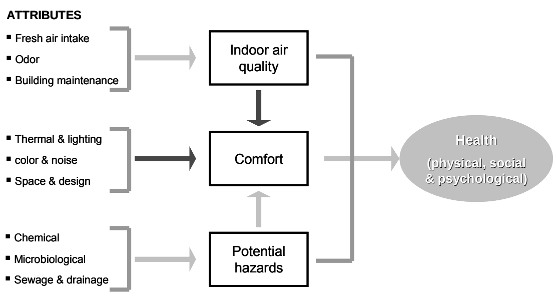

Figure 6. Attributes to health and safety in underground buildings: conceptual framework of health and building parameters.

The spatial characteristics are direct and easy to obtain from architects or their technical advisors, and even for the majority of aspects, some observations can be made by field visits,. Therefore, this is an additional information that can be gathered and related to the findings of the research, but will not be the scope of this thesis. Environmental benefits are healthier indoor air within underground spaces due to healthier building materials and continuous fresh air provision.

LESSONS LEARNED

Earth shelters, as a passive means to conserve energy, have been intensively analyzed to determine the impact of various climates on their performance. As would be expected of any passive and, therefore, climate-sensitive approach, earth sheltering performed significantly better in some climatic regions than in others. In general, those areas with significant temperature extremes (either summer or winter or both) and low humidity were best suited. While all areas potentially gained some benefit from the concept, in certain areas other passive strategies appear to be more appropriate (Wendt, 1982, pp. 33-48). International and local examples are outlined in the following.

The US experiment thru the EPA and LEED Systems

There is a lot of information available to help determine the environmental preference of various building designs, materials, products, and processes. By encouraging all design and construction contractors to seek out the available information and to ask manufacturers and suppliers to provide it, the Environmental Protection Agency (EPA) had access to the best available information on the subject. As more customers begin asking for environmental attribute information, additional manufacturers will begin providing it and designing products that maximize each positive attribute, while minimizing the negative ones.

In establishing standards for certification, the LEED[1] system has borrowed from regulations and guidelines set by various government agencies and nonprofit organizations. For instance, in establishing the LEED's VOC emission standards, the Green Building Council referenced adhesive and sealant limits established by two California air quality agencies, paint and coating standards formulated by Green Seal, and a carpet testing procedure from the Carpet and Rug Institute of Dalton, Georgia (John Tibbetts, 2002, pp. 553-9).

The Egyptian Environmental Policy Program

The Egyptian Environmental Policy Program (EEPP) attempts to improve the regulatory and institutional framework within which the society operates. It recognizes that a plethora of stresses to

[1]LEED - Leadership in Energy and Environmental Design - is a third-party certification program and an internationally accepted benchmark for the design, construction and operation of high performance green buildings.

Egypt's complex environment hinder efforts toward sustainable development. These stressors include inappropriate economic policies, ineffectual institutions, uninformed laws and regulations, obsolete technologies, and insufficient capital resources to secure the environment. (Cook, 1997, p. 10)

Innovative Structures Program

One goal of the Innovative Structures Program in assessing earth-sheltered housing was to attempt to identify the overall energy impact resulting from the fullest possible utilization of this concept. After reviewing the information available on which to make an evaluation, it is apparent that there are many gaps and weak points. To achieve a defensible quantitative estimate would require a tremendous amount of additional data. However, certain qualitative trends have appeared in the information collected to date. It is these trends that will form the conclusions of this report. Based on both monitored and calculated performance, it is clear that earth-sheltered houses are capable of very good energy performance. (Wendt, 1982, pp. 33-48)

EARTH SHELTERED SPACE DESIGN

1. An earth shelter must be healthy and safe for its occupants. Uncontrolled air movement and the presence of moisture have often contributed to the onset of pathogen and allergen growth indoors. Often misunderstood or underestimated in the past, media attention and homeowner education in the advanced communities have increased the need to construct a healthier underground space. (Frank, 2006, pp. 1-3). To maintain adequate natural ventilation, three general designs have been developed (DOE, 2007, pp 1-8):

   a. *Atrium (or courtyard)* plan—an underground structure where an atrium serves as the focus of the house and the entry into the dwelling;
   b. *elevational* plan, a bermed structure that may have a glass south-facing entry; and
   c. *penetrational* plan, which is built above or partially above grade and is bermed to shelter the exterior walls that are not facing south, Fig. 7.

The most energy-saving features attributed to underground space development can be grouped as the following (Barker, 1986, pp. 59-65).

Reduction of Conduction

A popular misconception about earth is that it is a good insulator. On the contrary, earth is a poor insulator, particularly when compared to commonly available insulating materials used in building construction.

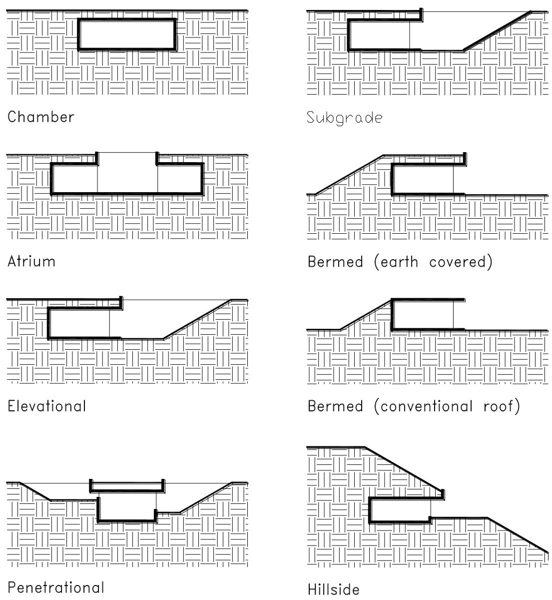

Figure 7. Classification of earth-sheltered space use by fenestration and ground-surface relationship

But even a poor insulating material can insulate effectively if it is massive enough. The fact that heat loss must flow vast distances makes earth a suitable blanket in which to wrap a building, Fig. 8.

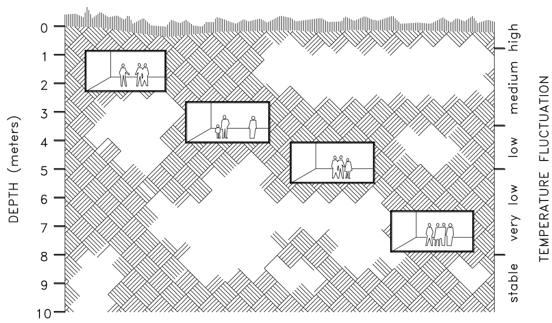

Figure 8. Schematic illustration of soil heat gain fluctuation in the subterranean house at different depths. (Golany, 1982).

Flattening peak space conditioning loads

The temperature of the earth just a few meters below the surface is stable in the 5-15°C range all year long. When the weather is extremely cold, the earth is a source of heat. Likewise, when the weather is extremely hot, the earth provides a source of cooling. Energy is needed only to overcome the difference between the earth temperature and a comfortable temperature, thus flattening the peak energy requirements for space conditioning. The result can be smaller heating and cooling systems that lower initial construction costs in addition to reducing operating expenses. In essence, the earth moderates the environment in which the building is located.

Controlling air infiltration

The third factor in saving energy through earth sheltering is the reduction of infiltrated outside air. With the earth covering most of the envelope of a building, the building can be made more airtight. In surface structures, up to 35% of heat loss can often be attributed to air infiltration. However, too "tight" construction can cause the build-up of indoor air pollutants, which some experts say can be far unhealthier than the worst outdoor urban smog. An earth-sheltered building offers greater opportunity to control the rate of outside air supply to the interior of a building.

Cooling through evaporation

The fourth principle deals with the natural absorption and dissipation of solar energy associated with an earth-covered roof. Such roofs are usually planted with grasses or ground cover to retard erosion and to improve the appearance of the building. The vegetation absorbs the sun's rays before they reach the earth. In addition, the natural evaporative process from plant materials has a cooling effect that helps prevent a buildup of heat on the building's roof, thus reducing cooling costs. (Barker, 1986, pp. 59-65).

BRIDGING EARTH SHELTERS' ENVIRONMENTAL DESIGN TRENDS TO GREEN INTERIORS

An earth sheltered space must be healthy and safe for its occupants. Uncontrolled air movement and the presence of moisture have often contributed to the onset of pathogen and allergen growth indoors. Often misunderstood or underestimated in the past, media attention and homeowner education in the advanced communities have increased the need to construct a healthier underground space. The main criteria to achieve underground green interiors are to achieve energy savings and reduce health implications.

Energy Savings

The most energy-saving features attributed to underground space development can be grouped as the following:

- *Reduction of conduction.* A popular misconception about earth is that it is a good insulator. On the contrary, earth is a poor insulator, particularly when compared to commonly available insulating materials used in building construction. But even a poor insulating material can insulate effectively if it is massive enough. The fact that heat loss must flow vast distances makes earth a suitable blanket in which to wrap a building.
- *Flattening peak space conditioning loads.* The temperature of the earth just a few meters below the surface is stable in the 5-15°C range all year long. When the weather is extremely cold, the earth is a source of heat. Likewise, when the weather is extremely hot, the earth provides a source of cooling. Energy is needed only to overcome the difference between the earth temperature and a comfortable temperature, thus flattening the peak energy requirements for space conditioning. The result can be smaller heating and cooling systems that lower initial construction costs in addition to reducing operating expenses. In essence, the earth moderates the environment in which the building is located.
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Earth Shelters' Interiors and Human Health Implications

The low air exchange rate in earth-sheltered structures presents a particular problem of moisture buildup resulting in excessively high indoor humidity. Mechanical dehumidification may be the only method practical during summer that can reduce humidity to about 50 percent. Mechanical ventilation is a more practical method of reducing humidity during winter, and an air-to-air heat exchanger can be used to prevent major heat losses during ventilation. Exposed walls and roofs of the structure require the same moisture protection as a conventional building. Below grade, the vapor pressure differential is not as large because of soil moisture and cold side temperatures that are generally higher than outdoors (Sherwood and Moody, 1989**,** pp. 133-4).

Healthy indoor environmental quality.

The quality of the air in buildings' indoor environment has become a key concern for health specialists, architects, and clients. The Environmental Protection Agency (EPA) developed a list ranking the health impacts of 26 top environmental problems, including hazardous waste sites, lead, outdoor and indoor air pollution, ground water contamination, chemical storage facilities, radiation, and ozone depletion.

The concern having the highest potential negative health impact was indoor air pollution, while the second ranking was indoor radon (Huelman, 2004, pp. 10-21).

Indoor environmental quality problems in earth sheltered buildings can take many forms but the main way to look at problems is to remember the three "P's" of indoor environmental quality: "Pollutants need a Pathway to People." If you eliminate any one of the 3 "P's," the problem goes away. When building or renovating a home, it is important to make good choices to avoid bringing pollutants into homes.

Many times the building materials we choose contain the pollutants–in fact, chemically sensitive individuals must be extra careful with their material selections. Some common pollutants found in homes are VOCs, mold, dust (pollen, dust mites, insulation fibers, etc.), carbon monoxide and other combustion products, radon, pesticides, and household chemicals (Barcik, 2005, pp. 30-1).

There are three basic aspects of indoor environmental quality that will be covered in this article—the sources of indoor air pollution, the health affects of common pollutants, and how to provide healthy indoor air (Huelman, 2004, pp. 10-21).

Pollutant sources

There are literally thousands of potential pollutants in a home. This section will focus on several main categories of indoor air pollution that can significantly afflict earth sheltered interiors.

Carbon monoxide.

The most serious effects are felt by individuals susceptible to oxygen deficiencies, including people with anemia, chronic lung or heart disease, and people living at high altitudes (Krarti, 2005, pp.113-6).

Nitrogen oxide.

The health effects of NOx on humans include nose and eye irritation, pulmonary edema, and bronchitis. Long-term exposure to NOx can cause pneumonia pulmonary fibrosis and emphysema (Krarti, 2005, pp.113-6).

PVC.

The Healthy Building Network and the Center for Maximum Potential Building Materials submitted to the U.S. Green Building Council (USGBC) a briefing paper that summarized the environmental health effects of polyvinyl chloride (PVC) building materials. Since that time, the USGBC's deliberations over PVC have continued and evolved. (Steingraber, 2004, pp. 2-5).

Volatile organic compounds (VOCs).

Volatile organic compounds (VOCs) comprise all organic compounds with appreciable vapor pressures and include organic acids, hydrocarbons, aldehydes, and ketones. Some VOCs are carcinogenic and have a significant human threat. For instance, benzene is a mutagen that changes the molecular structure of a cell and could lead to cancer (Moncef Krarti, 2005, pp.113-6). In addition they can cause eye, nose, and throat irritation; headaches, loss of coordination, nausea; and damage to the liver, kidneys, and central nervous system. Several of these organic compounds are known carcinogens. (Huelman, 2004, pp. 10-21).

Combustion Products

The process of burning any hydrocarbon fuel, which includes gas, oil, wood, etc., will result in carbon dioxide, water vapor, nitrogen oxides and several other potential pollutants depending on the type of fuel and equipment that is being used. Some of the other pollutants are carbon monoxide, respirable particles, sulfur dioxide, and aldehydes. With properly vented equipment, these pollutants are directed to the outdoors. However, with unvented equipment, improperly installed equipment, or equipment that is being challenged by a strong indoor negative pressure, some or all of the combustion gases can come into the building. (Huelman, 2004, pp. 10-21).

Radon.

Radon is a colorless, odorless, radioactive gas that is released as uranium when radium radioactively decays. In Minnesota, the rocks and glacial soils contain uranium and radium. When radon or its radioactive decay products are inhaled, they can cause irreversible cell damage in lung tissue that could lead to lung cancer. Builders should follow the new radon-resistant construction standards to minimize the change of elevated radon levels in their new homes. In general, this would include a number of below-grade sealing techniques, an aggregate layer beneath the floor slab, a sealed sump basket, and a vent pipe and electrical service to the attic for a future active sub-slab mitigation system (Huelman, 2004, pp. 10-21).

Biologicals.

This is one of the newest and may be one of the biggest indoor air pollution concerns. This category includes mold, dust mites, bacteria, pollen, and viruses. By controlling the relative humidity, many of these biological contaminants can be minimized. For instance, house dustmites, which are the source of one of the most potent allergens, will only grow in a warm and damp environment (Huelman, 2004, pp. 10-21).

Respirable Particulates.

This is a broad class of solid pollutants that can be inhaled deeply into the airways and lungs. These particles are frequently attributable to combustion, smoking, and biologicals. The health effects include eye, nose, and throat irritation; respiratory infections and bronchitis; and lung cancer. These particles can be minimized by using a high-efficiency air filtration unit on forced-air heating and cooling systems. Remind the home buyer to replace filters and to maintain the system. If any wood-burning equipment is going to be installed, the doors must fit tightly (Huelman, 2004, pp. 10-21).

Environmental tobacco smoke.

The health concerns for smoking and even “secondhand smoke” continue to build. Tobacco smoke includes a complex variety of pollutants, many of which are known carcinogens. Of course, smoking is a personal choice and beyond the control of the builder. However, if you know that a smoker will be buying your home, you may want to discuss ventilation strategies that would quickly and efficiently remove pollutants from areas that might be used for smoking (Huelman, 2004, pp. 10-21).

Asbestos and lead.

In the past decade we have heard a lot about asbestos and lead. Asbestos exposure can induce abdominal cancers and lung disease, and high lead exposures can impair mental and physical development. However, for newer homes, asbestos and lead are usually not an issue. Lead and asbestos have virtually been eliminated from common building products. For existing homes, it may be necessary to have a qualified contractor encapsulate or remove asbestos or lead-containing materials (Huelman, 2004, pp. 10-21).

Lead paint was used for more than a century for both interior and exterior surfaces. Painters and other tradesmen in proximity to lead paint can suffer effects from lead including loss of appetite, nausea, vomiting, fatigue, moodiness, and joint or muscle aches. Severe health problems include damage to the central nervous system resulting in tremors, seizures, convulsions, and wrist or foot drop, in which muscle or nerve damage causes deformities of those parts of the body. Acute lead poisoning can be fatal (John Tibbetts, 2002, pp. 553-9).

DESIGN GUIDELINES

Moisture Control and Enhanced Building Durability

Earth can be used to minimize the amount of exposed surface area of a building. Mounds of earth (berms) on the north side can considerably reduce the heat loss in that area. Prevailing winter winds (which usually come from the north or northwest) will carry away heat faster from an exposed north wall than from any other exposed building surface. It is best to minimize exposed wall surface area on the west and north sides (Huelman, 2004, pp. 10-21).

One way of preventing excessive exposure of a building to the elements is to place it underground. Humidity levels, however, may increase in underground spaces during the summer, which can cause condensation on the interior walls. Installing insulation on the outside of the walls will prevent the walls from cooling down to earth temperature; however, it also reduces the summer cooling effect of the walls, which may be viewed as an advantage in hot temperatures.

Mechanical air conditioning or a dehumidifier is often necessary to solve the humidity issue. Proper ventilation of closets and other closed spaces should keep the humidity from becoming a problem in those areas (DOE, 2007, pp 1-8). In the past decade the number of moisture-related complaints and call backs has been on the rise. Below is a list of the keys to effective moisture control.

- Airtight construction to keep interior moisture from condensing in wall and ceiling cavities,
- High R-value windows with warm-edge designs to reduce window condensation, and
- Mechanical house ventilation to control interior moisture levels (Huelman, 2004, pp. 10-21).

Moisture abatement strategies within earth shelters’ development

Besides the wind catchers' system and earth pipes, Figure 9 and 10, air movement can be directed to the earth-integrated building through open patios. They have a unique configuration in which air gradients are created when air moves above the building.

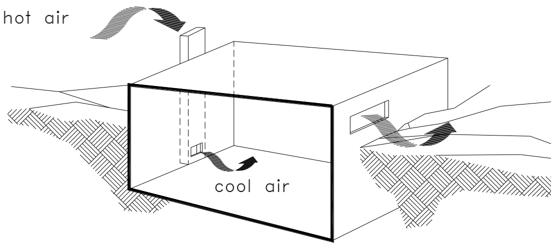


Figure 9. An air-circulation system with ability to reverse flow as prevailing wind shifts

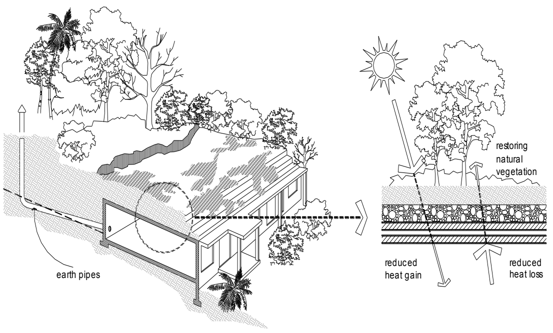
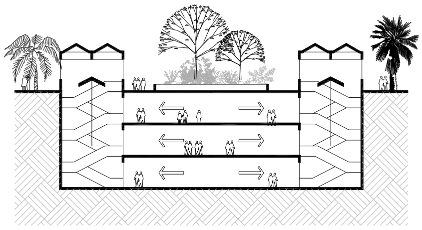
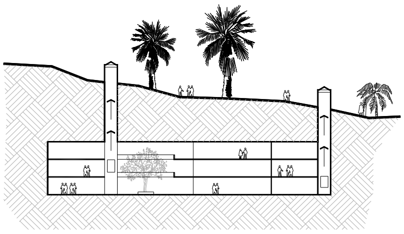


Figure 10. Earth Pipes and earth roof treatments

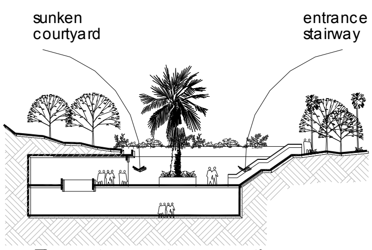
Innovative entrance design, means of shadowing, and patio treatments created for wind direction are illustrated in Fig. 11, 12, and 13.



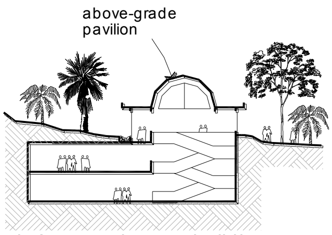
a. Shallow subterranean structure utilizes conventional egress techniques



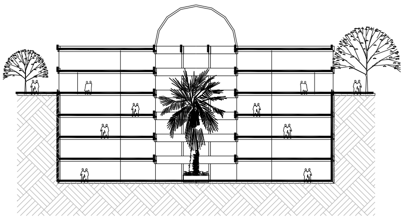
b. Elevators may be the only feasible means of egress in deep isolated subterranean space



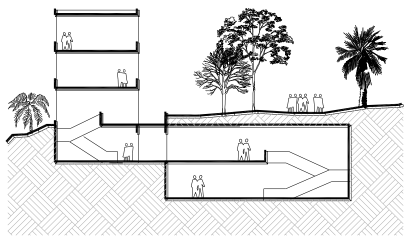
c. The entrance to an earth-integrated shelter through a sunken exterior courtyard



d. A cut-and-cover building with an above-grade entrance pavilion



e. Entrance occurs through the above-grade portion of the structure



f. The enterance to the earth-integrated structure occurs through an adjacent above-grade structure

Figure 11. Alternative patio design forms for combined subterranean and semi-subterranean buildings.

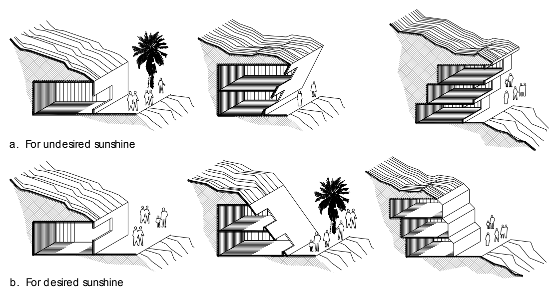


Figure 12. Cross sections of earth shelters showing means of shadowing

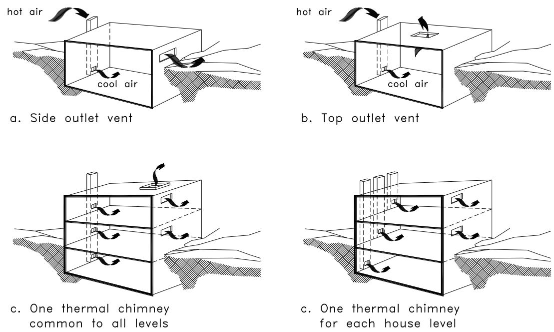


Figure 13. Innovative means of wind direction

Abatement of methane gas from leaking sewage.

As another face of the problem, all urban sites can be threatened with methane gas from a leaking sewing line, while suspended ground floors in older buildings are not ventilated. (Oliver) A precaution against soil gas is to design for a passive sub-slab depressurization system. This involves at least one 100-mm pipe, open at both ends. The lower end is set into a layer of clean, crushed rock at least 100-mm thick that lies immediately below the floor slab. Air is induced within this rock layer to enter the open end of the pipe, Fig. 14 (Stein and Reynolds, 2000, pp. 347-348).

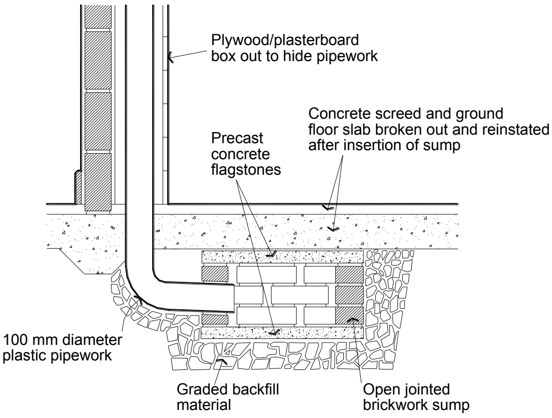


Figure14. Cross-section showing construction of a radon sump. (Thomas, 2005).

Reducing Environmental Impacts with Smart Use of Sustainable Building Material

Materials and products can be chosen for their reduced environmental impacts, from the insulation inside building walls, to floor material, to the quality of the indoor air, designing a healthy interior environment is vital to living a healthy life. The following indicates criteria of smart use of sustainable building materials to reduce their environmental impacts and maintain better health conditions in earth sheltered interiors:

a. *Use of low and zero VOC paint and finishes.*

b. *Installation of high-efficiency lights and appliances. LED and fluorescent lighting have improved dramatically in recent years and are now accommodating better affordable indoor environments. High-efficiency appliances offer both economic and environmental advantages over their conventional counterparts.*

c. *Use of wood and other renewable products increases occupant's health and productivity.*

d. *Use of natural light; placement of windows, Fig. 15. (Ranzi et al, 2006, pp. 3-4; 12).*

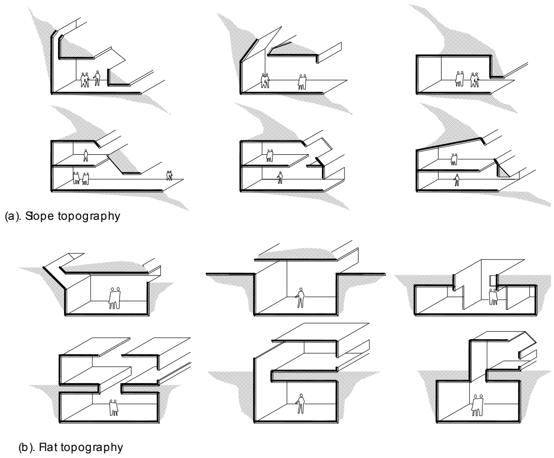


Figure 15. Orientation of an earth-integrated complex to obtain maximum daylight penetration at: a) slope topography and b) flat topography

Approaching Lifetime Risk Assessment in Earth Sheltered Spaces

Three different approaches to lifetime risk assessment for a chronic exposure of general public to dangerous indoor environmental pollutants in underground spaces are developed in Fig. 16.

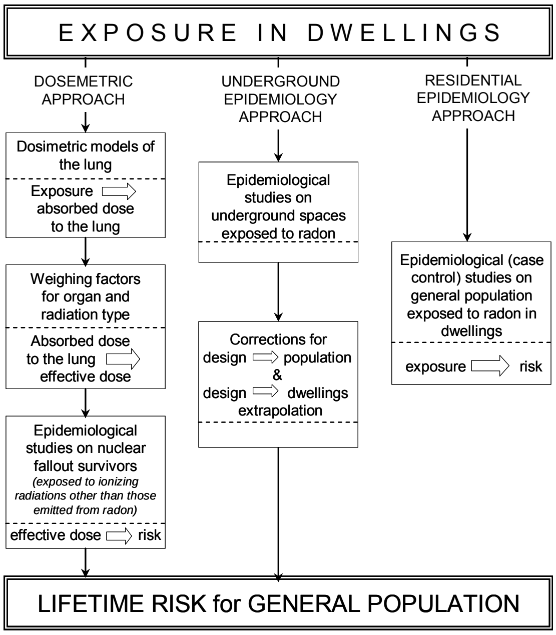


Figure 16. Lifetime risk assessment for a chronic exposure of building users to dangerous indoor environmental pollutants in underground spaces

In Fig. 17, the omissions at schematic design identified in the case study and the associated building symptoms in the operating phase are shown.

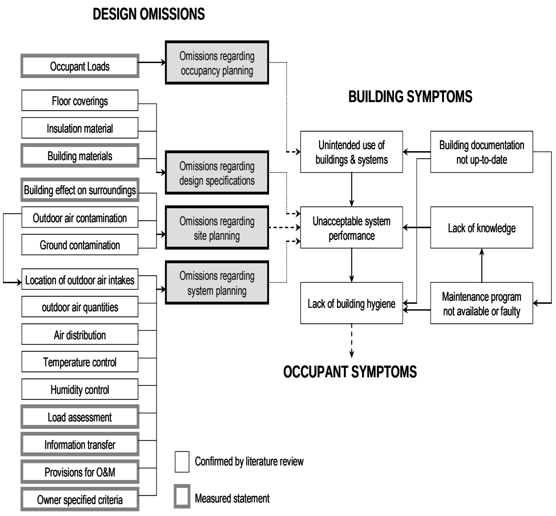


Figure 17. Schematic design omissions and suspected building symptoms in the operation phase - per case study. (Metzger, 1999).

The design omissions indicate that their effects on the problems during building operation have not been validated. It was suggested in the hypothesis that problems with occupant well-being can be prevented by a systematic review of the schematic design. A conceptual model is developed in Fig. 18.

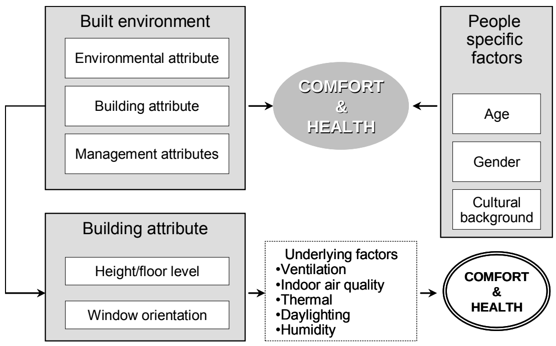


Figure 18. Conceptual model to satisfying architectural design and health requirements in underground space development

CONCLUSION AND RECOMMENDATIONS

The conclusion of this paper outlines the main points of an action plan to be established in the following directions:

- Coordination and information sharing across government agencies, health organizations, health care providers.

- Earth sheltered buildings composed of many interrelated systems. A building's overall performance is a function of interactions among these systems, of interactions with building occupants, and of operations and maintenance practices.

- Educators and the general public in addressing environmental health issues of underground space development and use.

- Identification and reduction of environmental health threats to living conditions in underground space.

- Identification of resources available to health care providers related to protecting human health in underground facilities.

- In an era where traditional energy sources are shrinking and other renewable trends are unpredictable, it seems to green industry professionals that countries that continue to allow architectural applications to be built and developed with outdated technologies and techniques are doing their current and future residents a great disservice.

- It is recommended that local Planning Board will take responsible steps to ensure that all underground development's long-term economic and social stability is protected.

- National, regional and local policies should be prepared to provide guidelines, criteria and classifications for assessing appropriate uses of underground space, identifying geologic conditions, defining priority uses and resolving potential utilization conflicts. Site reservation policies should be established for important future uses and for especially favorable geologic condition.

- Building Regulations should specify that all new underground space must be fitted with an inactive radon sump. The sump can be activated at a later stage to reduce radon concentrations if this is found to be necessary. For houses built in High Radon Areas the installation of a radon barrier as well as a sump is required.

- The underground interior space must be designed to provide comfortable environment, acceptable humidity level, and adequate ventilation to overcome indoor environmental quality problems, and compensate for images of stuffiness or dampness.

- It is highly recommended for architects and material specifiers to gather as much pollutant information for your building products as possible, so you can help your customer select materials and finishes that will not emit gas and harmful pollutants.

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